TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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TANK TESTS OF A MODEL OF THE HULL OF THE NAVY PB-1 FLYING BOAT - N.A.C.A. MODEL 52

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SUMMARY

A model of the hull of the Navy PB-1 flying boat was tested in the N.A.C.A. tank as part of a program intended to provide information regarding the water performance of hulls of flying boats of earlier design for which hydrodynamic data have heretofore been unavailable. Tests were made according to the general method over the range of practical loadings with the model both fixed in trim and free to trim. A free-to-trim test according to the specific method was also made for the design load and take-off speed corresponding to those of the full-scale flying boat.

The resistance obtained from the fixed-trim test was found to be about the same as that of the model of the NC flying-boat hull, and greater at the hump but smaller at high speeds than that of a model of the Sikorsky S-40 flying-boat hull.

INTRODUCTION

The program of work at the N.A.C.A. tank includes the testing of models of flying-boat hulls that have been service-tested on full-scale flying boats and are of historic interest in that they were important steps in the development of this type of craft. Tank tests of such models make available hydrodynamic data that were not easily obtained at the time the hull was built, especially in the case of the older designs. The information obtained from these investigations may prove to have considerable value when applied to the development of new hull forms.

The PB-1 flying boat was built by the Boeing Airplane Company and put into service in 1925. The design specifications (given in Automotive Industries for September 3, 1925) were as follows:

Gross load	24,000 lb.
Useful load	12,531 lb.
Wing area	1301.5 sq. ft.
Engines (2)	800 hp. each.
Cruising speed	90 m.p.h.
Top speed	112 m.p.h.
Stalling speed	66 m.p.h.
Climb	5,000 ft. in 10-1/2 min.

The shell of the hull below the water line was of duralumin; above, of plywood.

The lines of the full-size hull for use in preparing those of the model and the data regarding the position of the center of gravity of the complete machine for use in the specific tests were supplied the Committee through the courtesy of the Bureau of Aeronautics, Navy Department.

DESCRIPTION OF MODEL

The 1/6.59 full-size model of the hull of the Navy PB-1 made for these tests was designated model 52. The principal lines are shown in figure 1, and the offsets are given in table I. The model was shaped from a horizontally laminated shell of mahogany and finished in gray enamel, wet sanded and polished to give a smooth surface.

The particulars of the model and of the full-size flying boat are as follows:

	Model	Full-size
Length:		
Over-all	103.82 in.	57 ft. 0 in.
To second step	61.49 in.	33 ft. 9 in.
Of forebody to main step	46.92 in.	25 ft. 9 in.

	Model	Full-size
Beam	17.00 in.	9 ft. 4 in.
Gross load	83.4 lb.	24,000 lb.
Get-away speed	41.5 f.p.s.	72.5 m.p.h.
Depth of main step	0.68 in.	4.5 in.
Depth of second step	0.53 in.	3.5 in.
Center of gravity forward of step	7.41 in.	4 ft. 1 in.
Center of gravity above keel	15.1 in.	8 ft. 3-1/2 in.

Linear ratio model to full size	1/6.59
Designed trim	1.2°
Dead rise at step	22-1/2°
Angle of keel aft of main step	5° 20'
Angle of keel aft of second step	11° 38'
Beam:	
Percent of over-all length	16.4
Percent of length to second step	27.7
Percent of forebody length	36.2
Forebody:	
Percent of over-all length	45.2
Percent of length to second step	76.3
Center of gravity, distance forward of the step:	
Percent of over-all length	7.1

Percent of length to second step	12.0
Percent of forebody length	15.8
Center of gravity, distance above the keel:	
Percent of over-all length	14.5
Percent of length to second step	24.6
Percent of forebody length	32.2

The form of the hull of the Boeing PB-1 is similar to that of the famous NC flying boat that flew across the Atlantic Ocean in 1919. The forebodies of the two hulls are almost exactly alike except that the PB-1 has built-in spray strips. The afterbody of the PB-1 resembles that of an NC that has been cut off by a transverse step about one-half of the length from the main step to the sternpost. A long extension of the hull aft of the second step is provided to carry the tail surfaces on the full-size flying boat. The differences between the two hulls in angle of afterbody keel, angle of dead rise, and depth of step are very small. A tank test of a model of the NC hull has been reported in reference 1.

APPARATUS AND METHODS

The N.A.C.A. tank and its original equipment are described in reference 2. The model suspension has since been altered; its present form is shown diagrammatically in figure 2a. The towing girder is much smaller than before and is suspended by two steel tapes connected to counterweights and a dashpot. The girder rises and falls without changing its attitude and the trimming moment of the restrained model does not affect the load on the model. The purpose of the inertia counterweights shown in figure 2a is to cancel the effect of accelerations on the model and towing gear.

The apparatus used to measure the trimming moment is shown in figure 2b. The model is set at the desired trim by means of the adjusting screws. Trimming is restrained by trimming-moment springs clamped at the upper ends between knife edges attached to the structure of the towing gear. Deflections of these calibrated springs move the indicator arm, which in turn actuates the dial gage. The change in trim resulting from the deflection of the trimming-moment spring is so small (less than 0.1°) that it does not seriously affect the trim. The motions of the indicator arm are damped by an oil dashpot.

The fixed-trim set-up is easily changed to the free-to-trim set-up shown in figure 2c, by removing the trimming-moment spring. The model is then free to trim about the center of gravity, which is adjusted by means of counterweights on a vertical staff to coincide with the pivot. In the specific type of free-to-trim test, the hydrofoil and auxiliary tape shown by broken lines in figure 2a are required. The lifting force of the hydrofoil is applied to a bridle attached to the pivot.

Three types of test were made of model 52, general fixed-trim, general free-to-trim, and specific free-to-trim. The general fixed-trim test consists of a number of runs at constant speed and trim using a sufficient number of loads to cover the useful working range. The model is tested at a sufficient number of trims to determine the minimum resistance and corresponding trim for any load and speed within the range of the tests. This type of test gives more general information than does the specific test because it can be practically independent of the particular design specifications for load at rest and for take-off speed. The readings taken for each point are: resistance, trimming moment, and draft. The resistance includes the air drag on the portion of the hull above the water. Moments tending to raise the bow are considered positive. Draft is defined here as the vertical distance from the free water surface to the keel at the main step.

In the general free-to-trim test practically the same ranges of load and speed are covered as in the general fixed-trim test, with the model free to trim about the center of gravity. The hydrofoil gear required for the specific type of test is not used. At each speed the resistance and trim are measured for each of several arbitrarily selected values of the load. The data obtained are useful for calculating the water performance free to trim for a wide range of speed and load conditions. The same information can be obtained by cross-plotting the general fixed-trim moment curves and picking off the values of resistance corresponding to zero moment (free-to-trim condition). The resulting curves may be, however, slightly inaccurate at high speeds where values for resistance change more rapidly than moment with change in trim.

In the general tests, the loads on the model were applied in arbitrary even increments of a load coefficient, thus reducing the amount of cross-plotting required to obtain the performance curves.

In the specific free-to-trim test the load at rest corresponds to the design gross load of the flying boat. A calibrated hydrofoil simulates the lift of the wing at constant angle of attack and is set to make the model leave the water at a speed corresponding to the take-off speed of the full-size flying boat. Resistance, trim, and rise (vertical displacement of the center of gravity from the at-rest position) are read at predetermined intervals of speed.

In both types of free-to-trim tests the trim assumed by the model is influenced only by the water and air forces on the hull acting about the center of gravity. The trim assumed by the full-size hull may be considerably different from that of the model because the effects of the magnitudes and points of application of the other forces on the full-size flying boat are not provided for in the test set-up.

RESULTS

The nondimensional coefficients used in presentation of the data are as follows:

Load coefficient, $C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient, $C_R = \dfrac{R}{wb^3}$

Speed coefficient, $C_V = \dfrac{V}{\sqrt{gb}}$

Trimming-moment coefficient, $C_M = \dfrac{M}{wb^4}$

where Δ is the load on the water, lb.

w, specific weight of water, lb./cu.ft. (63.5 for these tests)

b, beam of hull, ft.

R, water resistance, lb.

V, speed, ft./sec.

M, trimming moment, lb./ft.

g, acceleration of gravity, ft./sec.^{2}

The data for the fixed-trim test are presented in figures 3 to 8; resistance coefficient C_R and trimming-moment coefficient C_M are plotted against speed coefficient C_V with load coefficient C_Δ as parameter.

In order to obtain the characteristics of the model at best trim, resistance coefficient, trimming-moment coefficient, and draft-beam ratio as obtained from the data of the fixed-trim tests were each cross-plotted against trim at selected values of speed coefficient with load coefficient as a parameter. From these cross plots, minimum resistance coefficient, best trim (trim for minimum resistance), trimming-moment coefficient at best trim, and draft-beam ratio at best trim were determined for each selected speed coefficient. Resistance coefficient, trimming-moment coefficient, and draft-beam ratio, all at best trim, are plotted against speed coefficient in figures 9, 10, and 11; best trim is plotted against speed coefficient in figure 12.

The results of the general free-to-trim tests are presented in figure 13. Resistance coefficient and trim are plotted against speed coefficient with load coefficient as a parameter. The results obtained from the specific free-to-trim test are plotted in figure 14. Resistance coefficient, trim, and rise/beam are plotted against speed coefficient.

Trimming-moment coefficients and draft/beam ratios at rest are plotted in figures 15 and 16. These curves are useful in calculating longitudinal stability and in determining water lines of the hull for various static conditions.

DISCUSSION

Resistance characteristics.- Both the general and the specific free-to-trim curves (figs. 13 and 14) show a peak in the resistance curves below the hump speed, which does not appear in the curves at best trim (fig. 9). In general, hump resistances occur at a little higher speed when the model is free to trim than when it is at best trim and are not more than 10 percent greater.

Trim characteristics.- In figure 12 the best trim reaches a maximum value at a speed somewhat below the hump and then falls off, first sharply, then more gradually. In the same figure it will be observed that the best trim at the load coefficient $C_\Delta = 0.05$ is considerably greater than at the load coefficient $C_\Delta = 0.025$, which indicates that best trim decreases abruptly with unloading at high speeds and light loads.

A comparison of the curves of figures 12 and 13 shows that the model assumes a trim considerably higher than best trim when running at and above hump speed.

Trimming-moment characteristics.- Large negative trimming moments produced by the water forces acting on the long tail extension occur at low speeds, as shown in figure 10. Again, if the model is allowed to trim at an angle smaller than best trim the trimming moment will be considerably reduced without appreciably increasing the resistance. Maximum positive trimming moments are not excessive.

Draft characteristics.- The curves of the draft-beam ratio are shown in figure 11. A comparison of figures 11 and 12 shows the relationship between change in draft and change in best trim. The draft as measured from the free water surface is, of course, not an accurate criterion for estimating either the mass of water displaced or the character of the flow at a particular speed and load, but a study of the variation in draft may lead to valuable conclusions concerning the identification of those portions of the hull responsible for any unusual increase or decrease in the wave-making resistance.

Spray characteristics.- Typical photographs of the model of the PB-1 running in the water are shown in figure 17. They illustrate a wide variation of loads and speeds but the trims at which the pictures were taken were in all cases near best trim except at speeds below the hump; in the latter cases, the pictures were taken at trims that were near free-to-trim attitudes because of the improbability that the pilot could hold best trim against the heavy negative moments at these low speeds. Figure 17a and figure 17b show the wave pattern at low speed and moderate load. The stern picture (fig. 17b) shows the heavy wave formation at these low speeds. Turbulent water can be seen coming from the second step.

Wave and spray formations at speeds just below and just above the hump are shown in figures 17c, d, e, and f. In figure 17d the stern is riding heavily in the water as indicated by the turbulent wave formation around it; in figure 17f the hull has risen in the water until the stern is barely touching the water. The spray from the forebody is thrown higher and wider in figure 17e than in figure 17c.

Figures 18a and 18b show the model running at a moderately high speed and with a load coefficient of C_Δ = 0.2. Although the under surface of the forebody is planing, the sheets of spray come back and strike the short afterbody. The tail extension is, however, clear of the spray. Figures 18c and 18d show the model in a simulated pull-off. The spray thrown aft from the main step is striking the afterbody and the tail extension. The trim, 9°, is considerably greater than best trim. Figures 18e and 18f show another simulated pull-off at the same trim angle but at a greater speed and lighter load. The resistance in both of these pull-offs is much geater than it would be at best trim as can be seen by comparing figure 7 with figure 9 for $C_\Delta = 0.025$ and $C_\Delta = 0.05$. Under the conditions represented by these simulated take-offs, but little moment is required to change the trim several degrees up or down.

<u>Comparison with performance of other American hulls</u>.- In figure 19 the load-resistance ratios of the models of the hulls of the PB-1, NC, and Sikorsky S-40 at selected speeds are compared. The hull of the S-40 (reference 3) has a straighter bottom on the forebody and a slightly smaller angle of dead rise than the NC or PB-1. The hulls of the PB-1 and NC have slightly greater Δ/R at high speeds than the S-40 but slightly smaller Δ/R at low speeds. There is but little difference in the load-resistance ratios between the hulls of the PB-1 and the NC at the speeds selected; in general, however, the hull of the PB-1 has a greater Δ/R than that of the NC at high speed and heavy loads and a smaller Δ/R at both high and low speeds for light loads. At hump speed the Δ/R of the PB-1 hull is smaller than that of the NC at all loads, but the difference is smallest at heavy loads.

CONCLUDING REMARKS

The performance of the model of the hull of the PB-1 reflects the close relationship of its form to that of the NC. The small difference in performance at low speeds between the two models is primarily caused by the long tail extension on the PB-1, which has a decided effect on the best trim. The slight differences in resistance at high speeds can be explained by the fact that the afterbody of the PB-1 has somewhat better clearance at high speeds and at heavier loads.

When the model of the PB-1 is compared with that of the S-40, the better performance of the latter at the hump may be explained in part by the fact that the keel and buttock lines of its forebody are straighter and that the afterbody produces more lift by virtue of its lower position relative to the forebody. At high speeds, the PB-1 is superior because of better clearance resulting from the location of the second step.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 9, 1936.

REFERENCES

1. Bell, Joe W.: Tank Tests of a Model of the NC Flying-Boat Hull, N.A.C.A. Model 44. T.N. No. 566, N.A.C.A., 1936.

2. Truscott, Starr: The N.A.C.A. Tank - A High-Speed Towing Basin for Testing Models of Seaplane Floats. T.R. No. 470, N.A.C.A., 1933.

3. Dawson, John R.: A Complete Tank Test of the Hull of the Sikorsky S-40 Flying Boat - American Clipper Class. T.N. No. 512, N.A.C.A., 1934.

TABLE I

Offsets for N.A.C.A. Model 52 (Boeing PB-1) Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line: Keel	Bottom [a]B1 1.82	Bottom B2 3.64	Bottom B3 5.46	Bottom B4 7.28	Chine	Spray strip	Deck	Deck [a]B1 1.82	Deck B2 3.64	Deck B3 5.46	Deck B4 7.28	Half-breadths: Chine	Knuckle	Gunner's cockpit	[b]WL1 3.64	WL2 5.46	WL3 7.28	WL4 9.11	WL5 10.93	WL6 12.75	WL7 14.57
F.P.	0.00	13.16							13.16														
1/4	.91	7.75					10.91		13.18					1.50		1.88				1.11	1.49	1.81	
1/2	1.82	6.41	9.02				10.47		13.20					2.32		2.32			1.11	1.85	2.32	2.32	
3/4	2.73	5.74	7.93				10.03		13.22					3.01		2.37			1.41	2.50	2.92	2.51	
1	3.64	5.26	7.38				9.62		13.24					3.62		2.10		0.18	1.75	3.22	3.40	2.49	
2	7.29	3.85	5.61	6.96	8.02		8.10	8.10	13.31	13.04	12.06	9.07		5.62	5.24			1.67	4.16	5.44	4.65	2.54	
3	10.93	2.83	4.14	5.25	6.19		6.84	6.75	13.39	13.16	12.39	10.79		6.98	6.46		1.10	4.03	6.94	6.45	5.35	2.94	
4	14.57	2.08	3.05	3.98	4.86	5.63	5.84	5.69	13.46	13.26	12.57	11.25	8.51	7.83	7.25		2.96	6.81	7.65	7.02	5.78	3.28	
5	18.21	1.52	2.33	3.15	3.95	4.73	5.12	4.93	13.54	13.35	12.71	11.50	9.19	8.26	7.68		4.76	8.26	8.02	7.32	6.04	3.55	
6	21.86	1.14					4.67	4.48	13.62	13.42	12.80	11.61	9.44	8.43	7.83			8.42	8.17	7.47	6.18	3.75	
7	25.50	.87					4.40	4.24	13.69	13.50	12.89	11.71	9.56	8.48	7.89			8.47	8.23	7.54	6.27	3.92	
8	29.14	.70					4.24	4.15	13.77	13.57	12.96	11.80	9.67	8.50	7.92			8.49	8.26	7.59	6.35	4.05	
9	32.79	.59					4.13	4.13	13.85	13.65	13.04	11.87	9.74		7.93			8.49	8.28	7.63	6.41	4.20	
10	36.43	.50					4.04		13.92	13.73	13.11	11.95	9.82					8.49	8.30	7.66	6.48	4.32	
11	40.07	.46					3.99		14.00	13.80	13.19	12.02	9.89					8.50	8.31	7.70	6.54	4.44	
12	43.71	.43					3.97		14.07	13.88	13.26	12.10	9.97					8.50	8.32	7.73	6.61	4.57	
Step, F.	46.92	.42					3.96																
Step, A.	46.92	1.10					4.64																
13	47.36	1.14					4.68		14.15	13.95	13.34	12.17	10.04	8.50				8.50	8.34	7.77	6.67	4.69	
14	51.00	1.48					4.99		14.23	14.03	13.41	12.23	10.08	8.43				8.43	8.31	7.76	6.70	4.78	
15	54.64	1.82					5.28		14.30	14.11	13.48	12.27	10.00	8.31				8.31	8.22	7.70	6.70	4.85	
16	58.29	2.15					5.53		14.38	14.17	13.51	12.28	9.84	8.11					8.05	7.60	6.65	4.90	
Step, F.	61.49	2.45					5.73							7.88									
Step, A.	61.49	2.98					6.26																
17	61.93	3.07					6.34		14.45	14.25	13.57	12.25	9.53	7.85					7.81	7.44	6.55	4.91	
18	65.57	3.82					6.94		14.53	14.32	13.61	12.19	8.83	7.52					7.51	7.21	6.42	4.89	
19	69.21	4.57					7.53		14.61	14.39	13.63	12.06		7.12						6.91	6.22	4.83	0.79
20	72.86	5.32					8.08		14.68	14.44	13.63	11.82		6.64						6.53	5.97	4.73	1.28
21	76.50	6.07					8.62		14.76	14.49	13.58	11.33		6.11						6.06	5.62	4.54	1.58
22	80.14	6.82					9.11		14.84	14.54	13.46	9.47		5.50						5.50	5.19	4.28	1.75
23	83.79	7.57					9.58		14.91	14.57	13.16			4.86							4.65	3.91	1.82
24	87.43	8.32					10.04		14.99	14.55	12.28			4.16							4.02	3.45	1.80
25	91.07	9.07					10.47		15.06	14.43				3.38							3.30	2.86	1.65
26	94.71	9.82					10.86		15.14	13.79				2.52							2.51	2.16	1.37
27	98.36	10.57					11.23		15.22					1.61								1.39	.96
28	102.00	11.32					11.57		15.29					.65								.58	.44
A.P.	103.82	11.69					11.74		15.33					.15								.15	.15

[a]Distance from center line (plane of symmetry) to buttock (section of hull surface made by a vertical plane parallel to plane of symmetry).

[b]Distance from base line to water line (section of hull surface made by a horizontal plane parallel to base line).

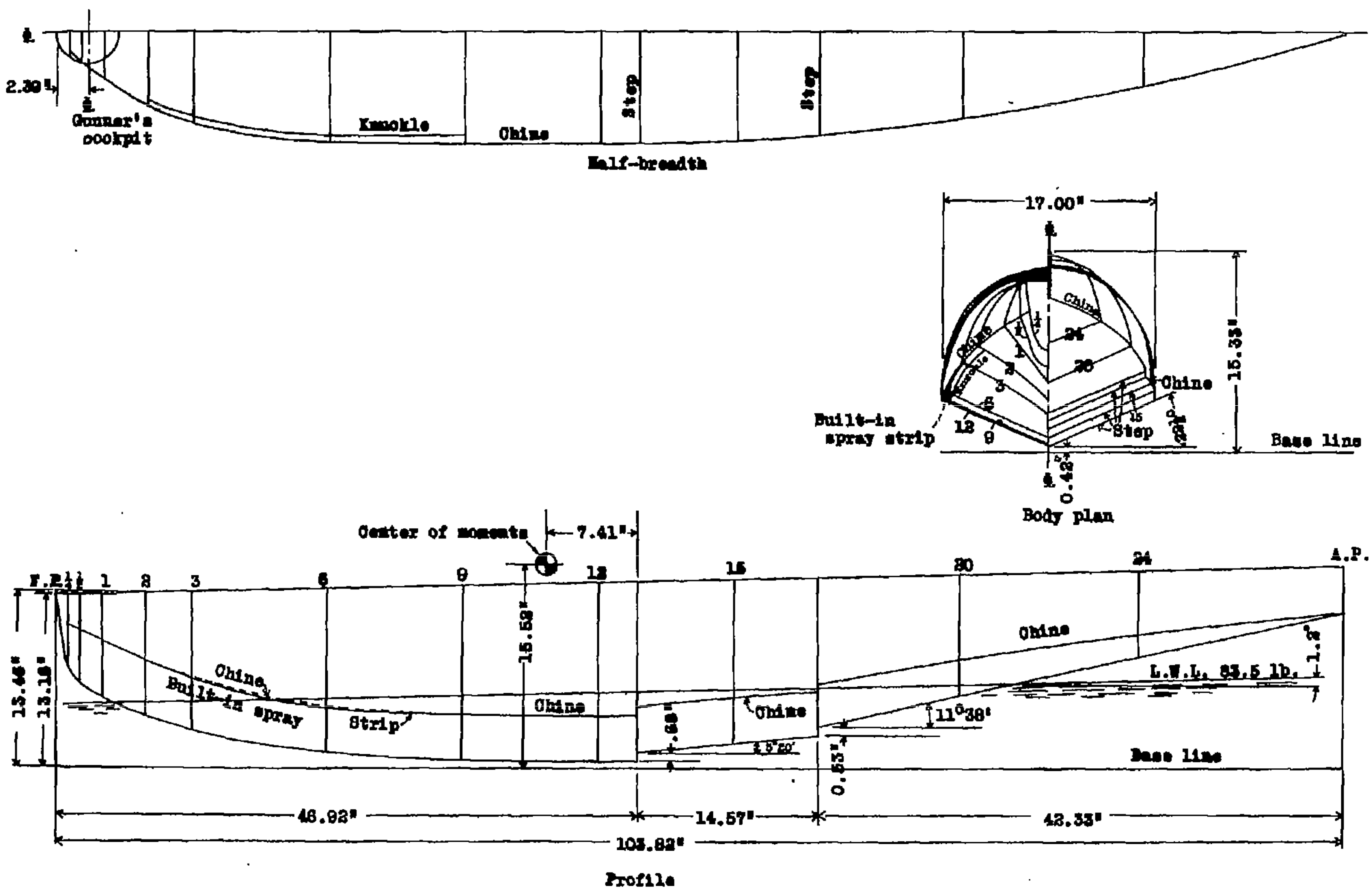


Figure 1.-Lines of N.A.C.A. model 52 (Boeing PB-1).

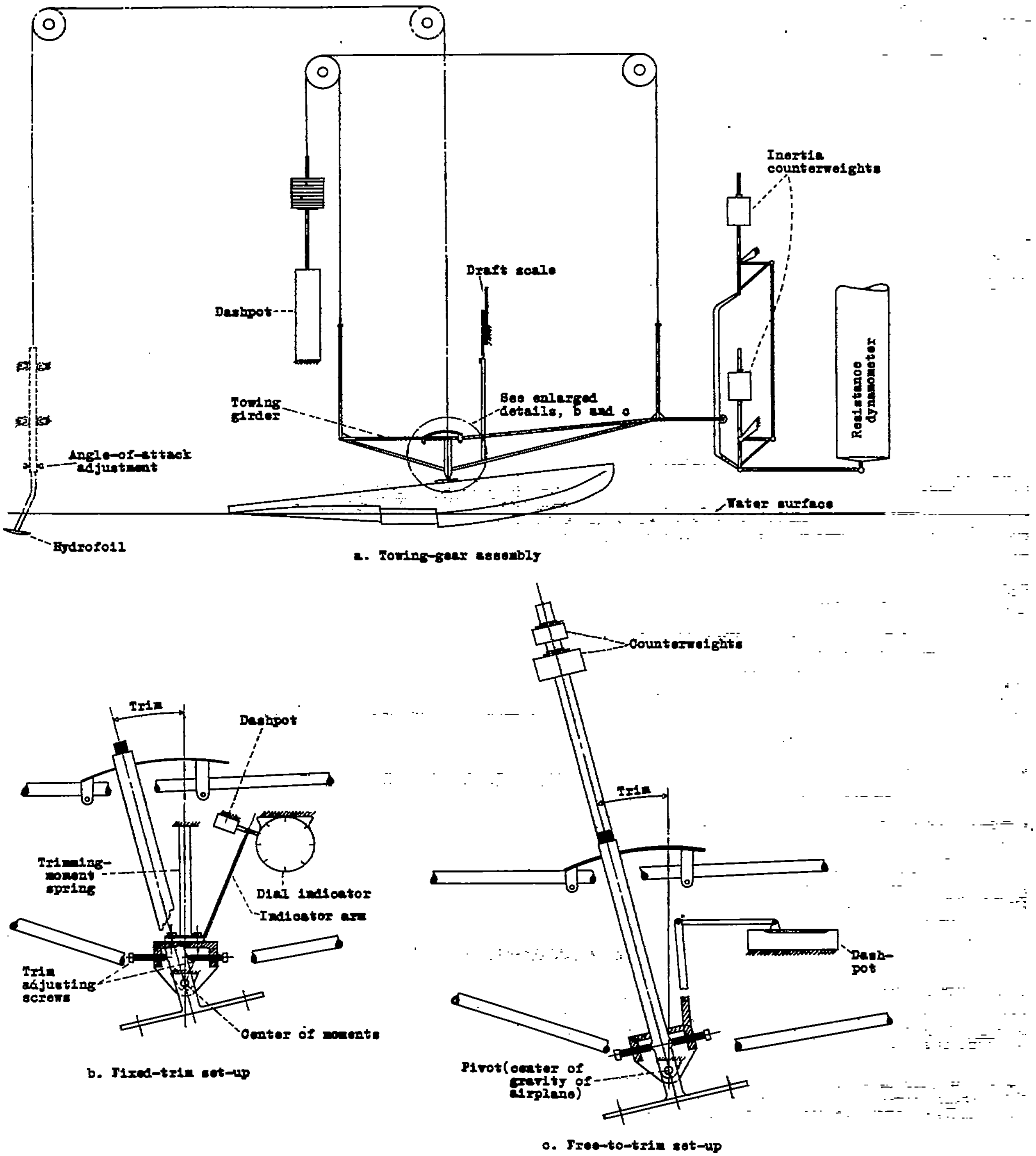


Figure 2.-Diagrams of set-ups for free-to-trim and fixed-trim tests.

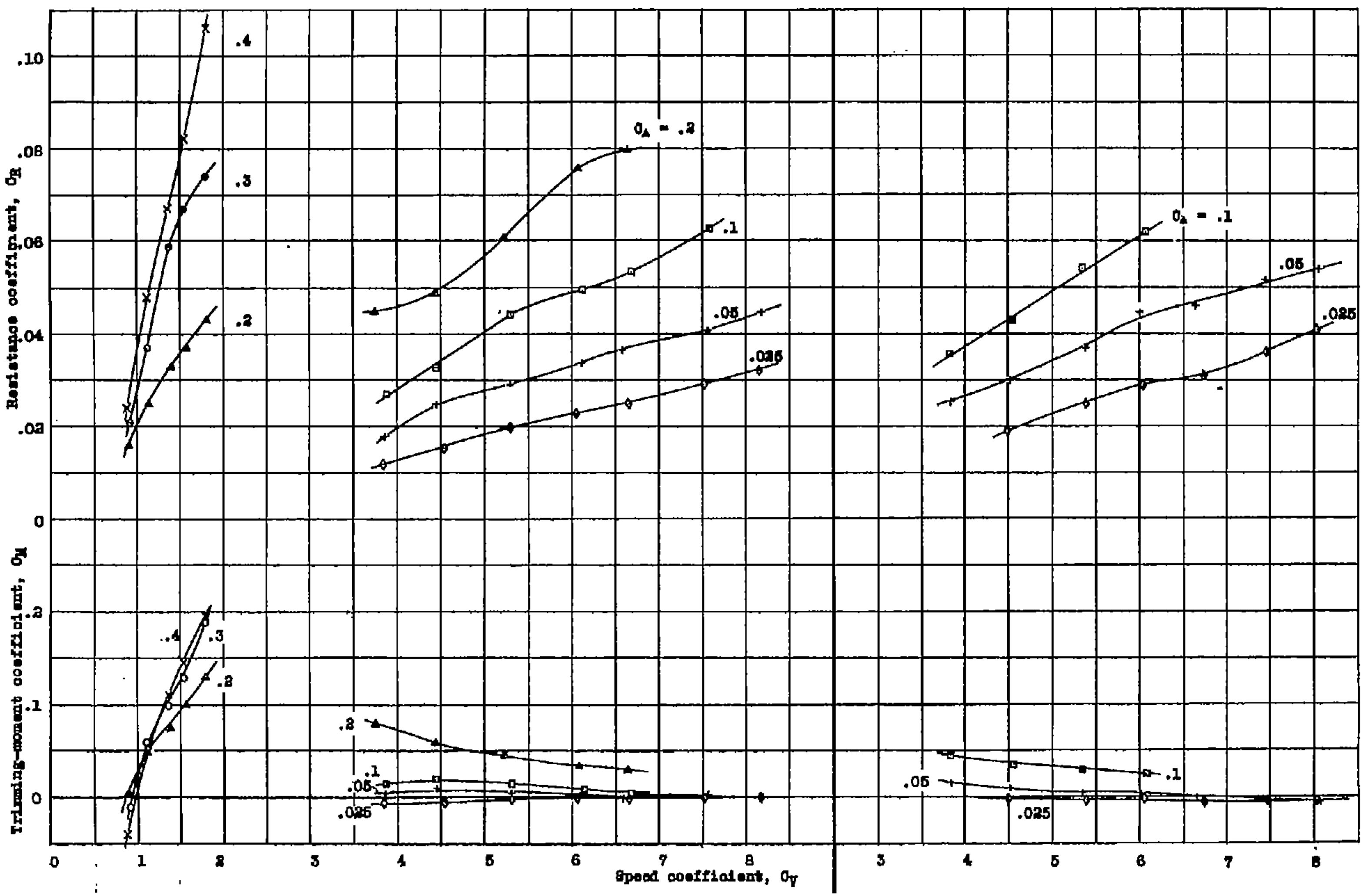


Figure 4.-Resistance coefficient and trimming-moment coefficient, $\tau = 3^0$.

Figure 3.-Resistance coefficient and trimming-moment coefficient, $\tau = 2^0$

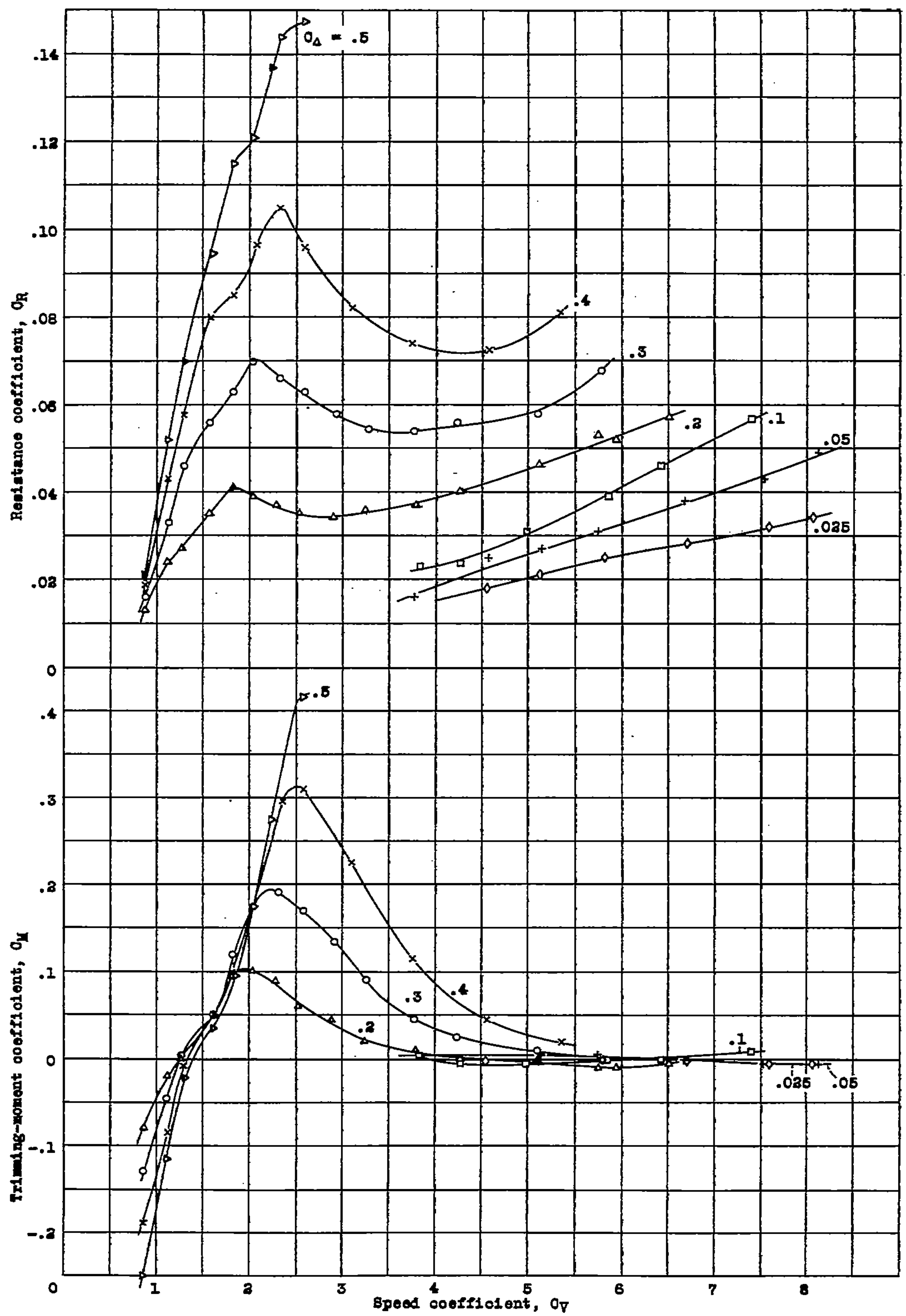


Figure 5.-Resistance coefficient and trimming-moment coefficient. $\tau = 5^\circ$

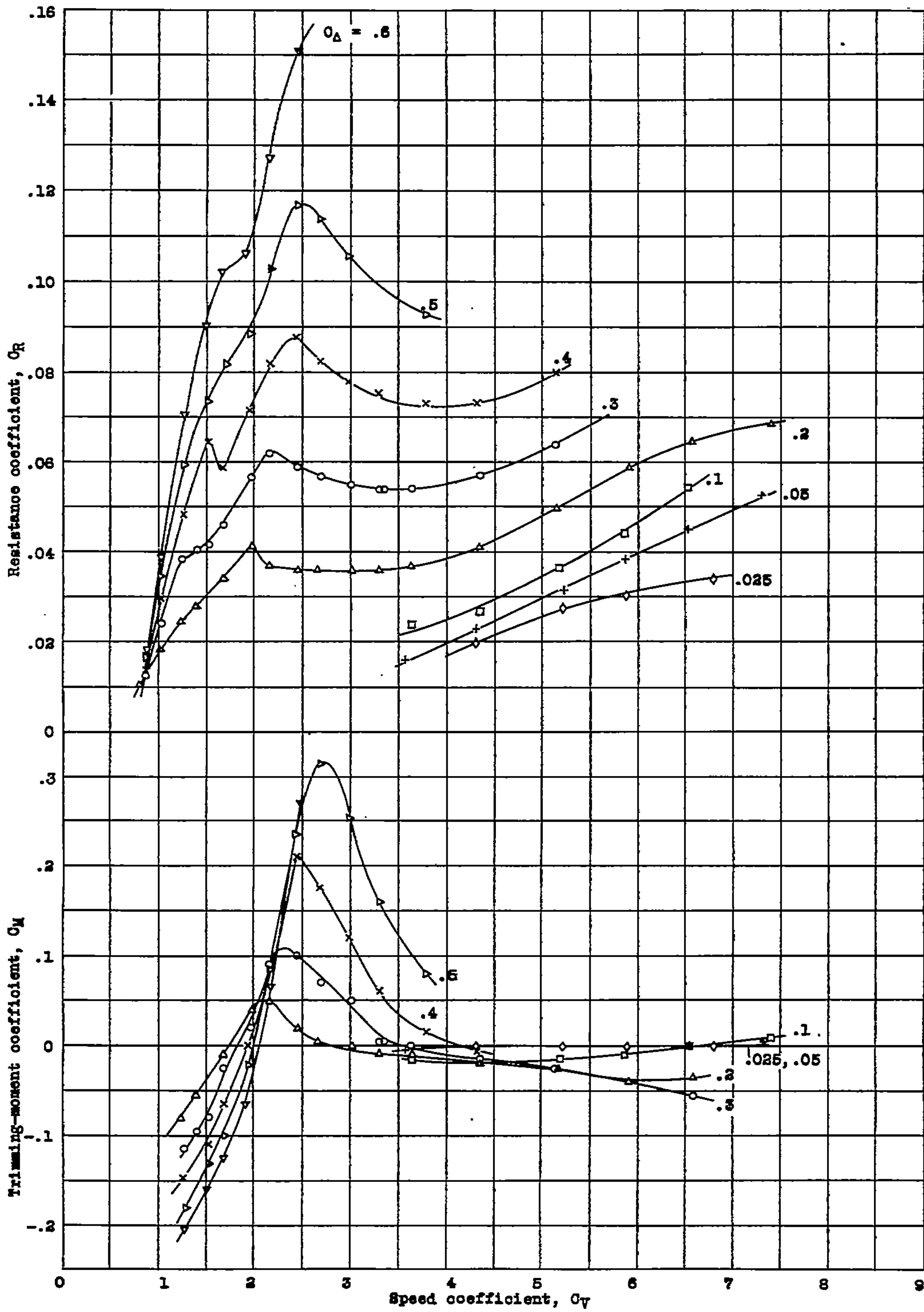


Figure 6.-Resistance coefficient and trimming-moment coefficient. τ = 7°

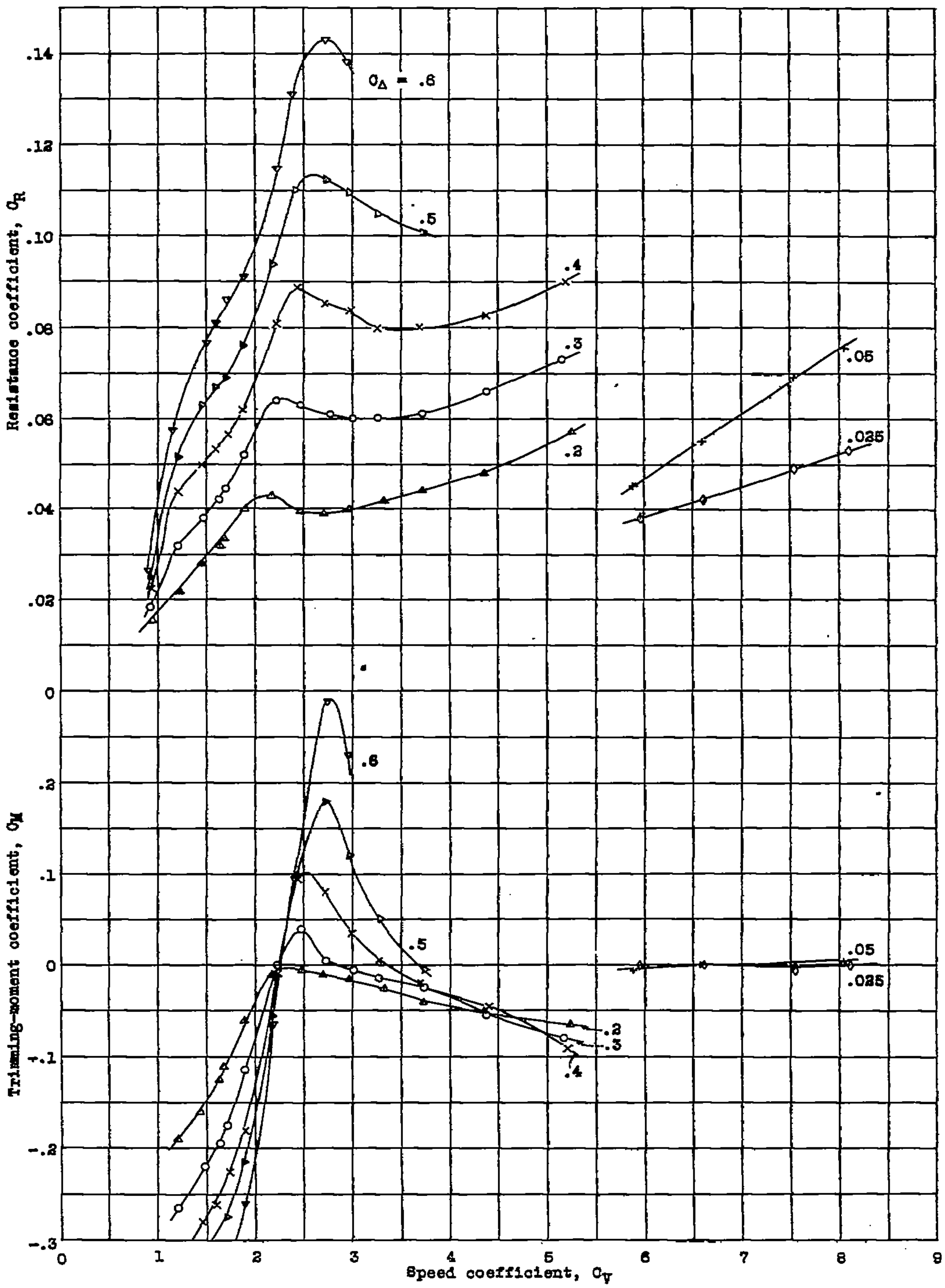


Figure 7.-Resistance coefficient and trimming-moment coefficient. $\tau = 9^{\circ}$

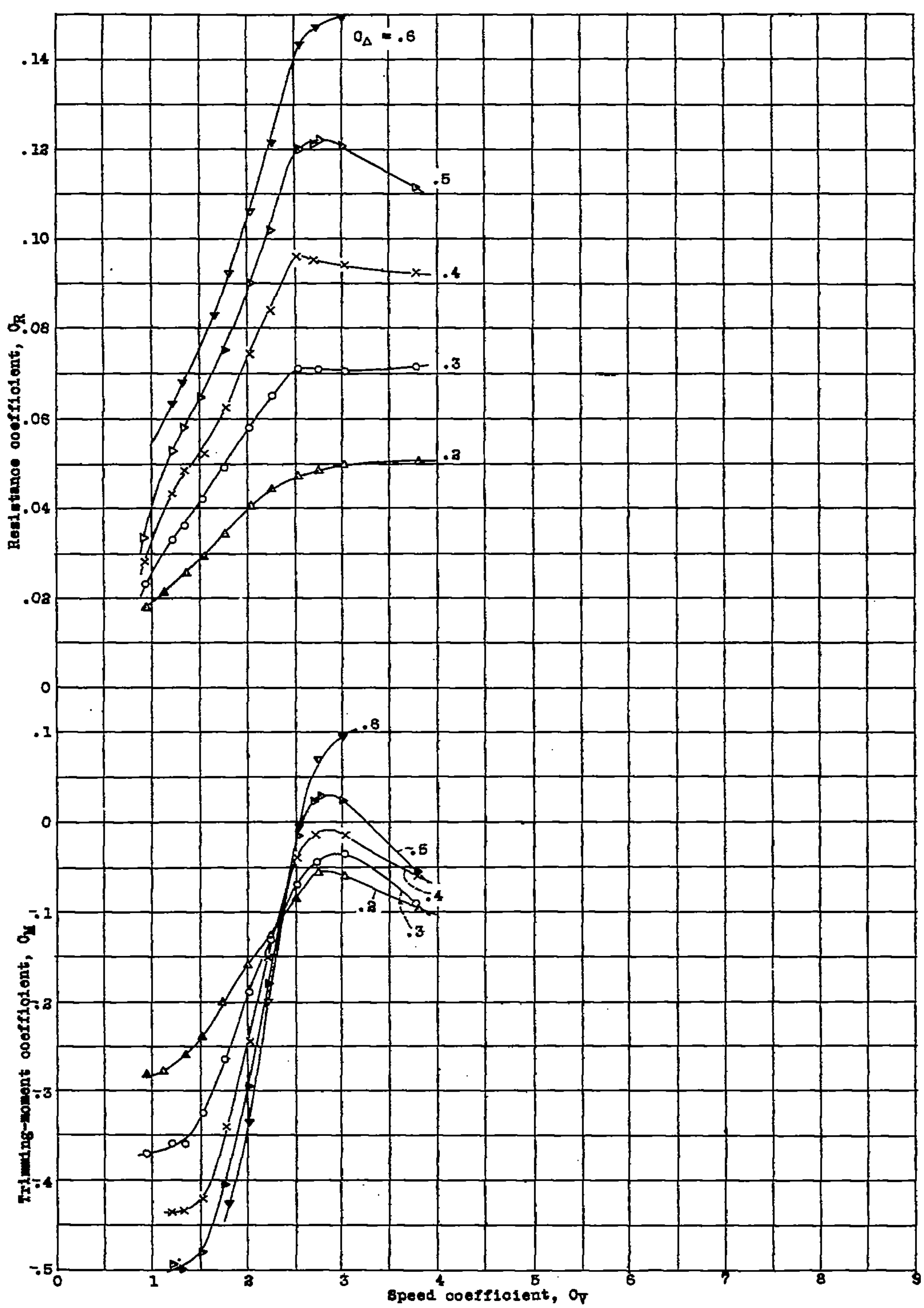


Figure 8.- Resistance coefficient and trimming-moment coefficient, $\tau = 11°$

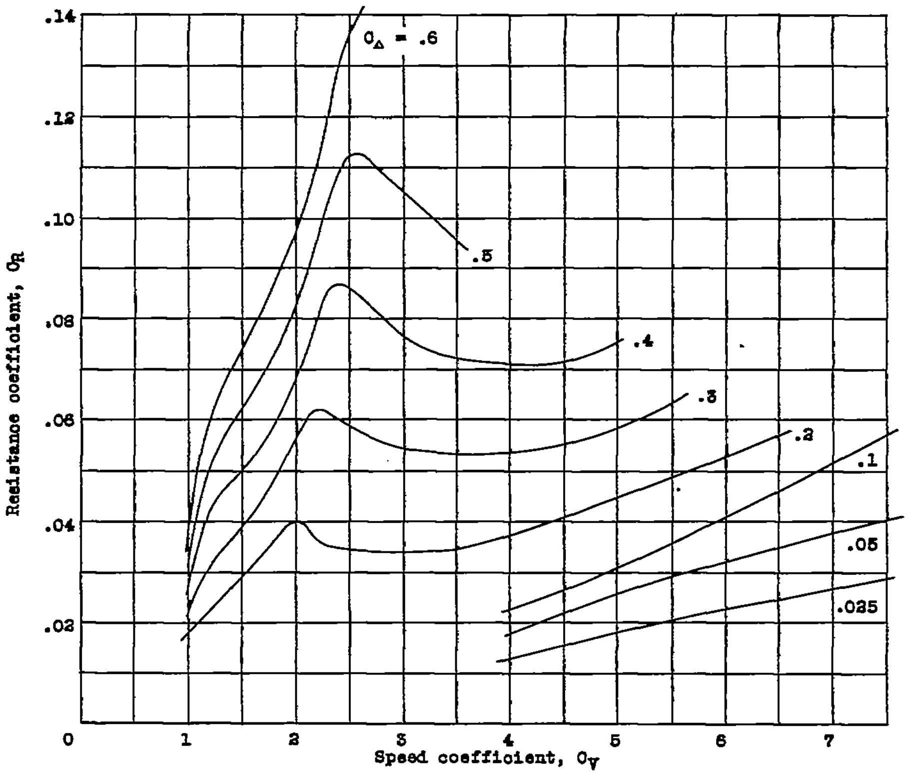


Figure 9.-Variation of C_R with C_V at best trim.

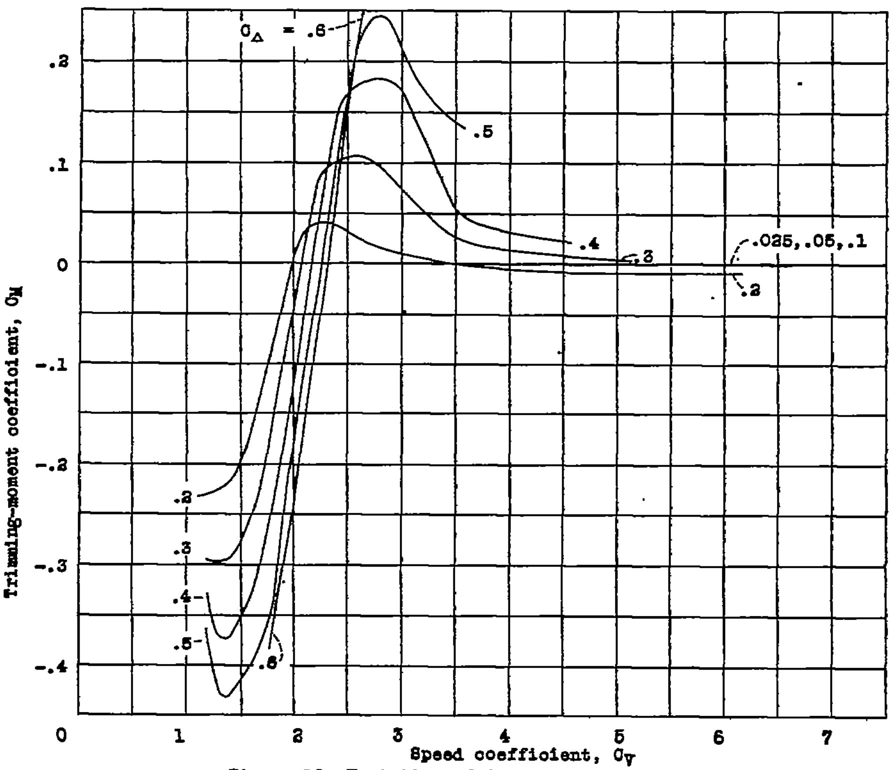


Figure 10.-Variation of C_M with C_V at best trim.

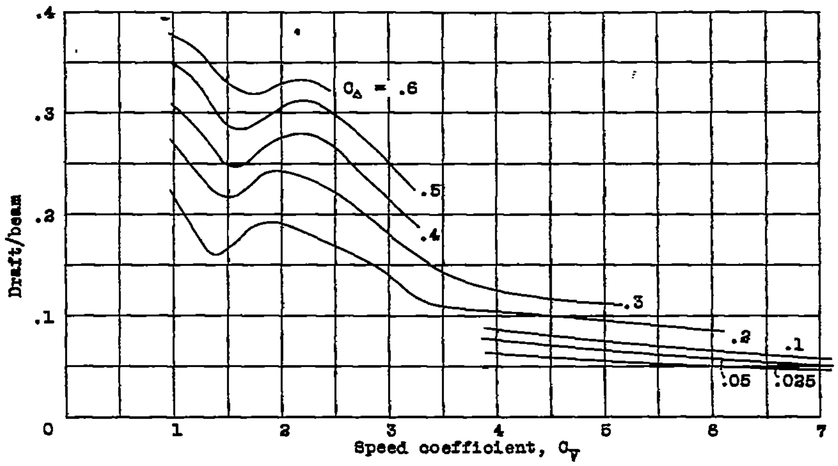


Figure 11.-Variation of draft/beam with C_V at best trim.

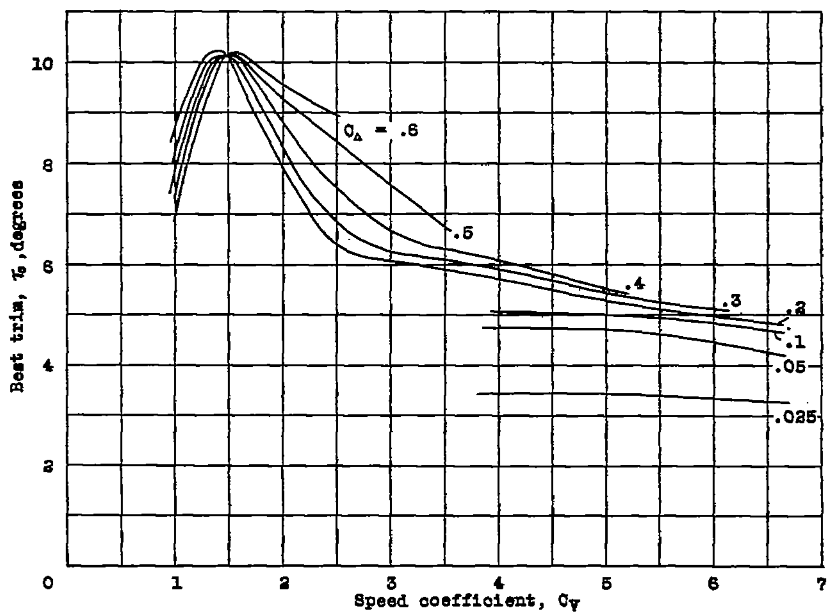


Figure 12.-Variation of best trim, τ_0, with speed coefficient, C_V

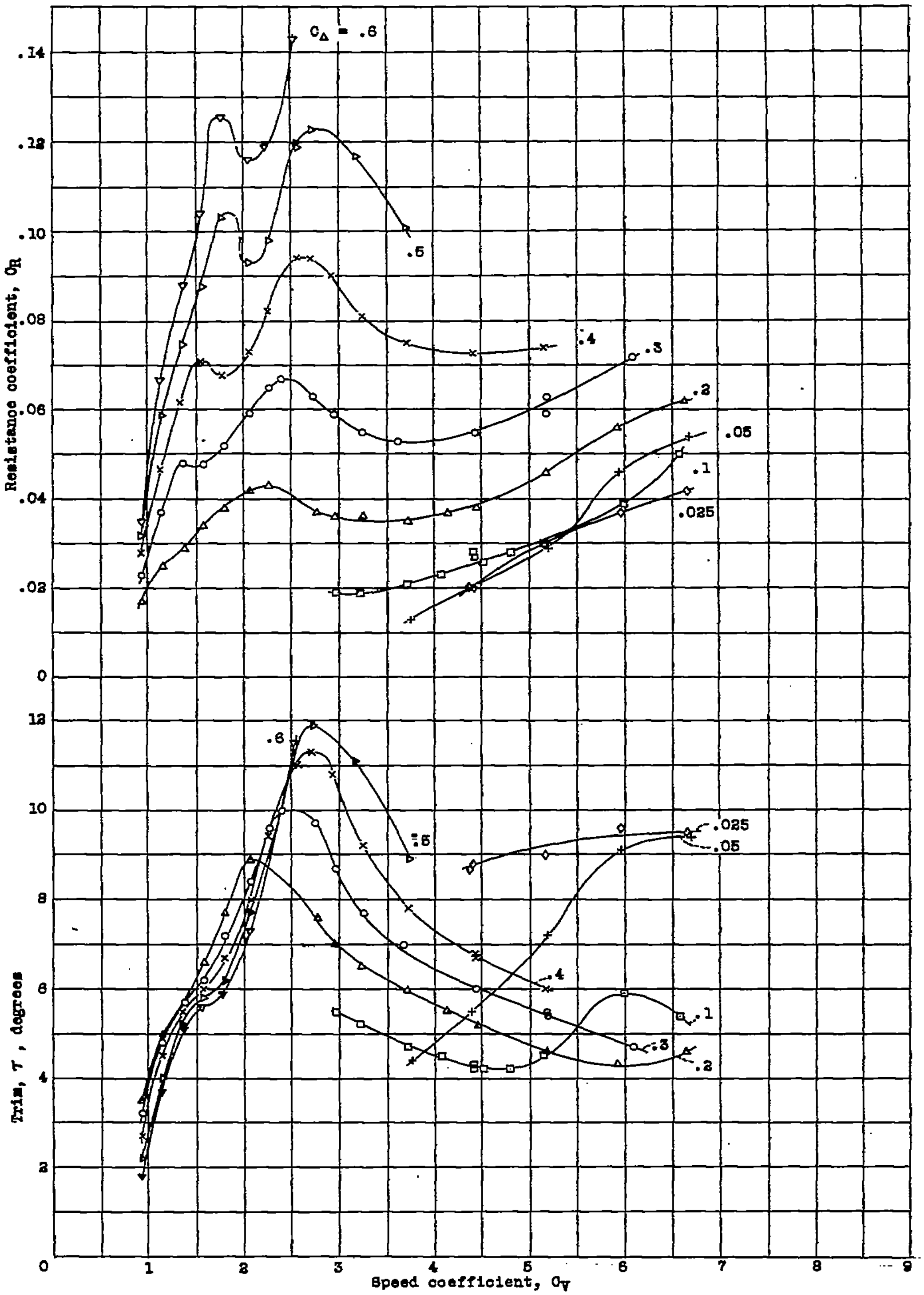


Figure 13.- Resistance coefficient and trim. General free-to-trim test.

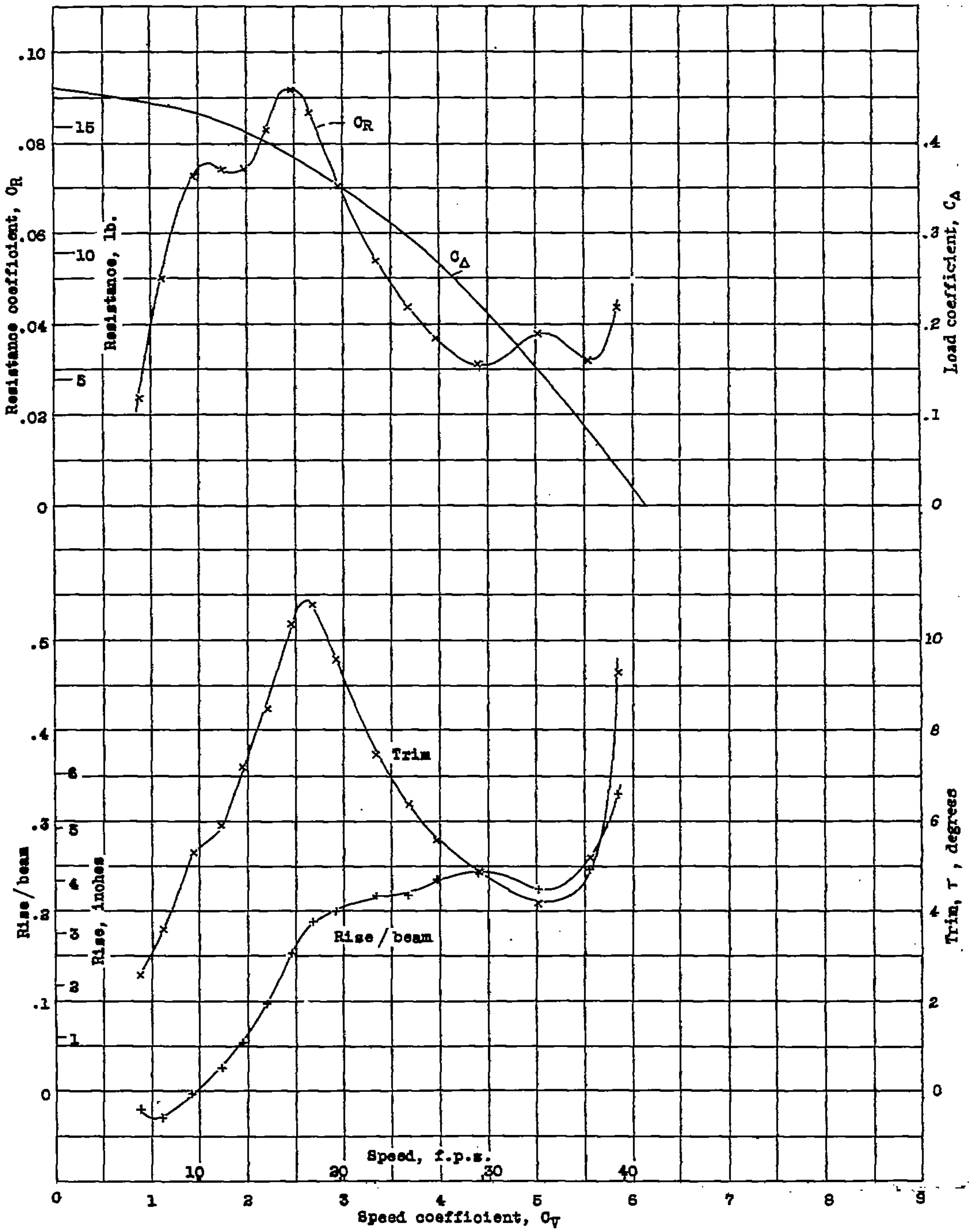


Figure 14.- Resistance coefficient, trim, and rise/beam. Specific free-to-trim test.

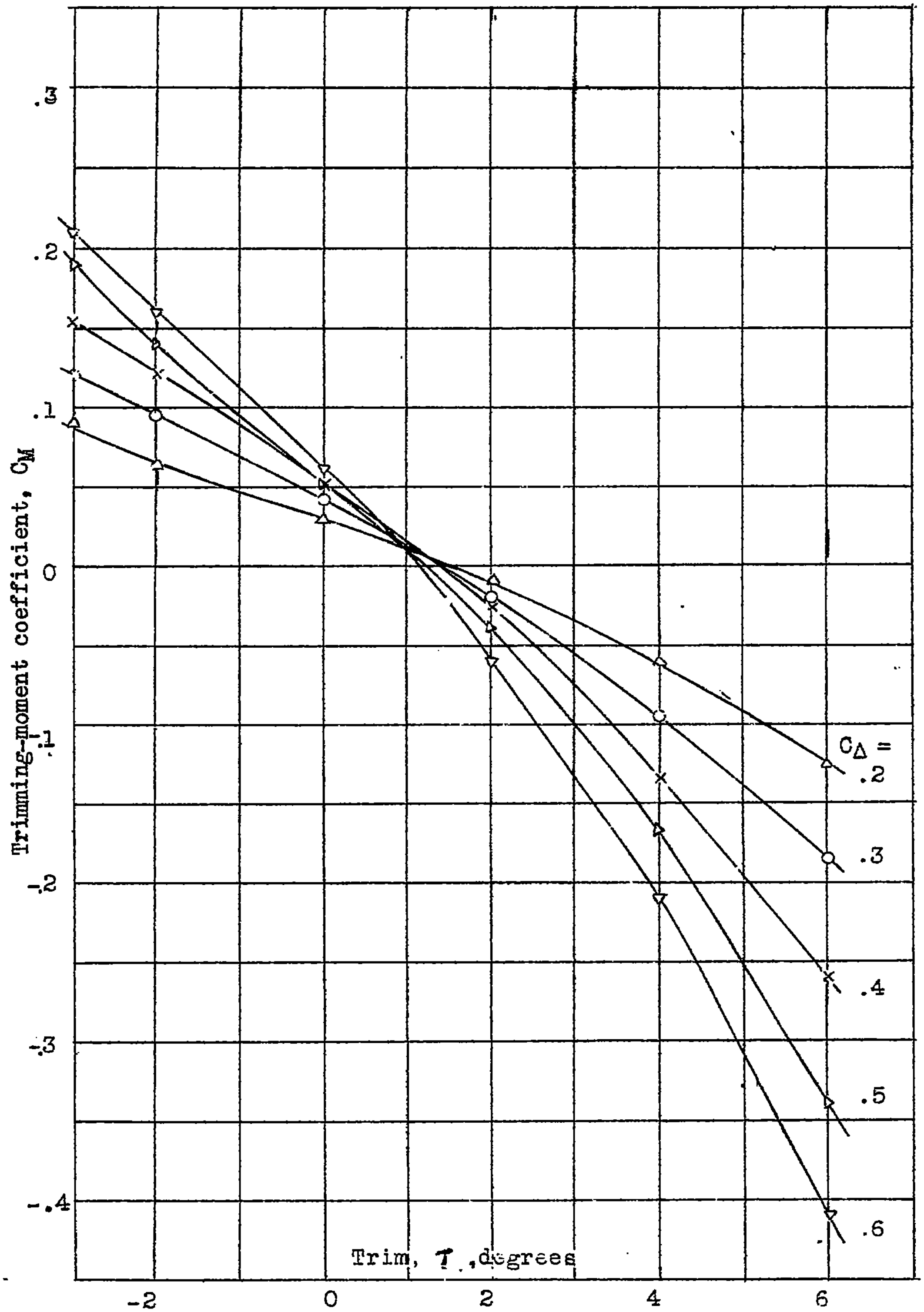
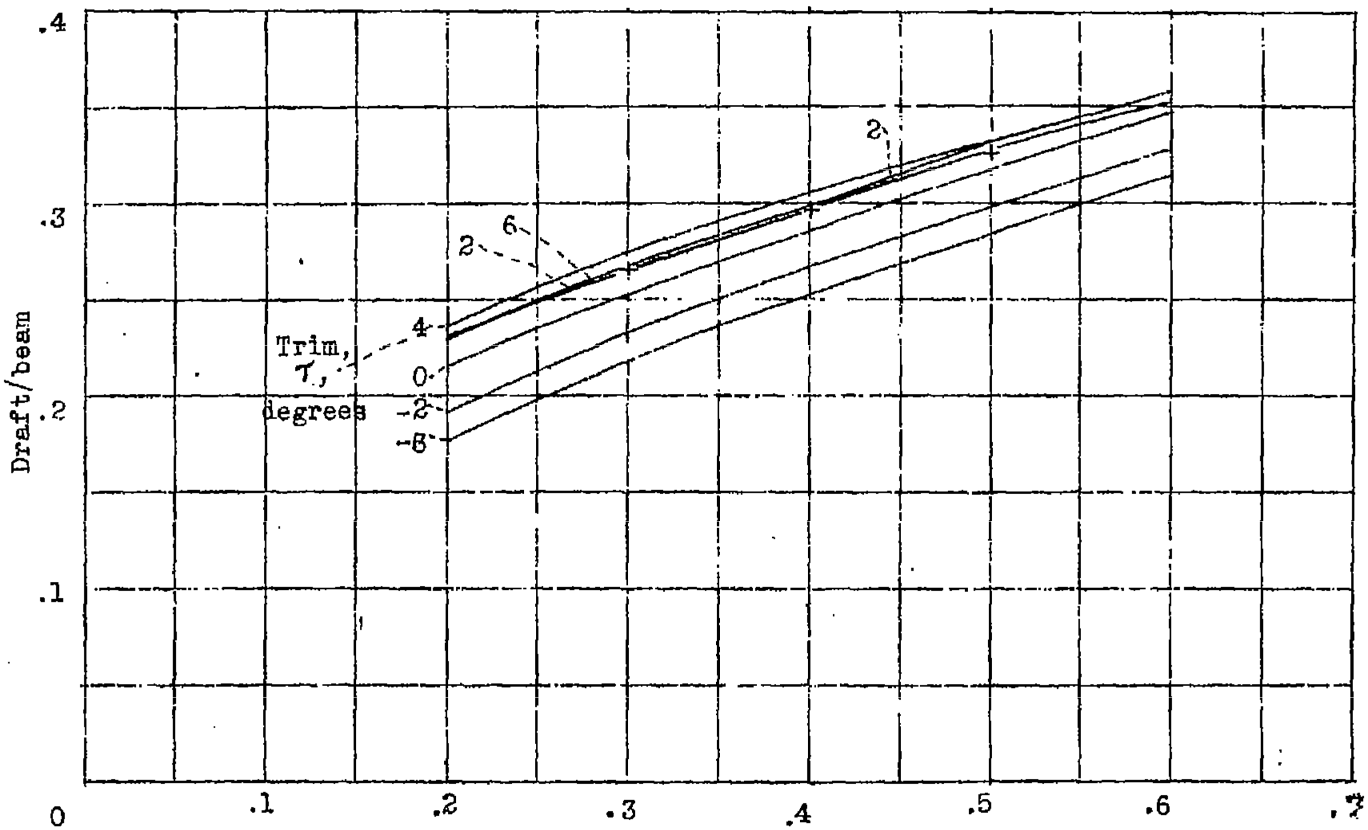


Figure 15.Trimming-moment coefficients at rest.



Load coefficient, C_Δ

Figure 16.- Draft-beam ratios at rest.

(a) (b)

$C_V = 1.26$; $C_\Delta = 0.5$; $\tau = 5^\circ$

(c) (d)

$C_V = 2.15$; $C_\Delta = 0.6$; $\tau = 9^\circ$

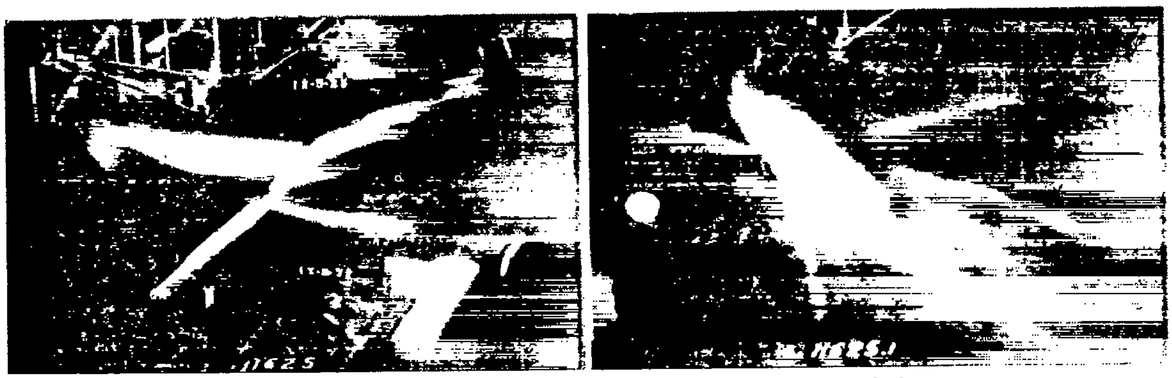
(e) (f)

$C_V = 2.70$; $C_\Delta = 0.6$; $\tau = 9^\circ$

Figure 17.- Spray photographs of the PB-1.

(a) (b)

$C_V = 5.15$; $C_\Delta = 0.2$; $\tau = 3^\circ$



(c) (d)

$C_V = 5.9$; $C_\Delta = 0.05$; $\tau = 9^\circ$

(e) (f)

$C_V = 7.35$; $C_\Delta = 0.025$; $\tau = 9^\circ$

Figure 18.- Spray photographs of the PB-1 for moderately high speed and two simulated pull-offs.

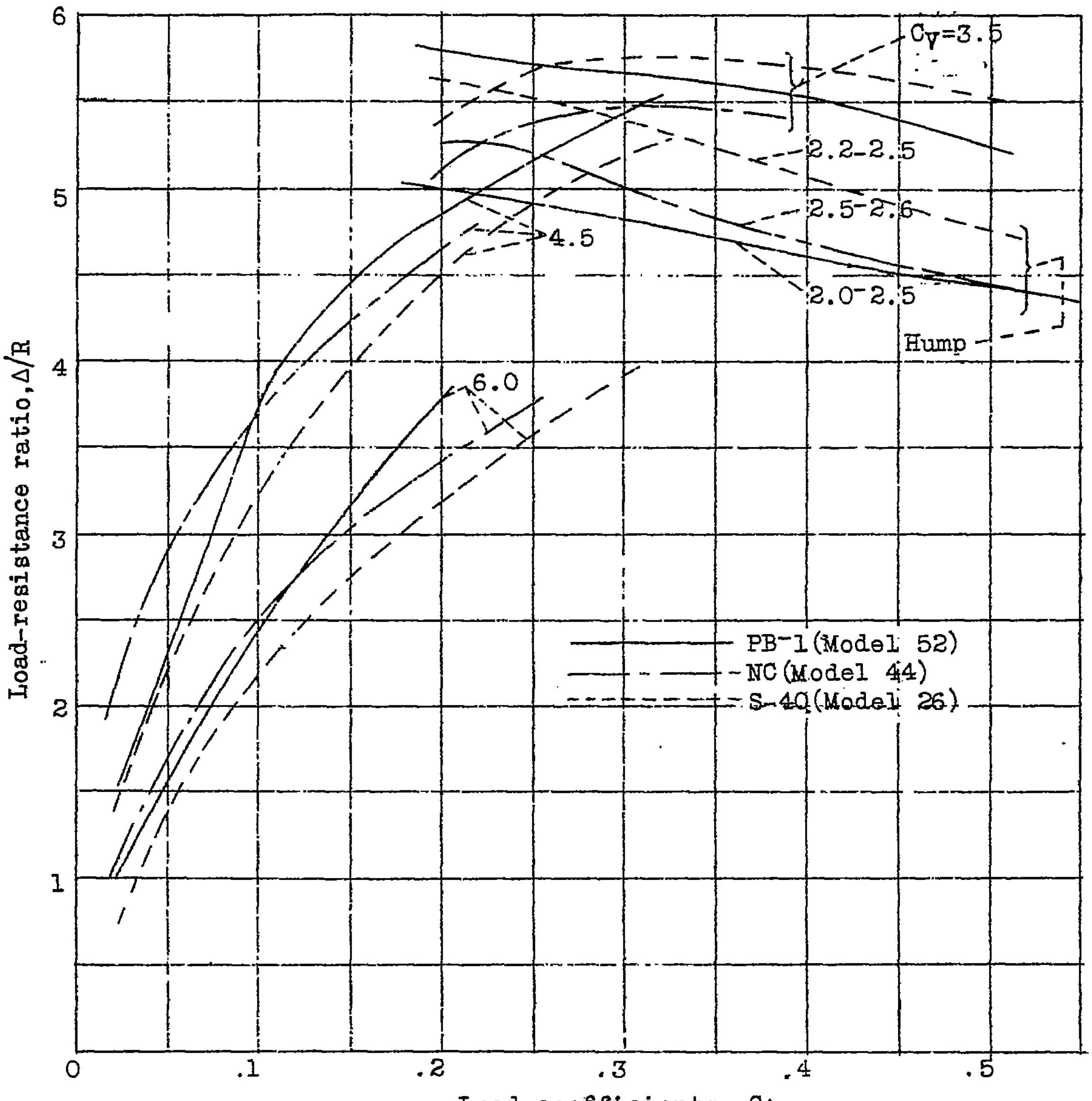


Figure 19.- Comparison of load-resistance ratios of PB-1, NC, and S-40 flying-boat hulls.